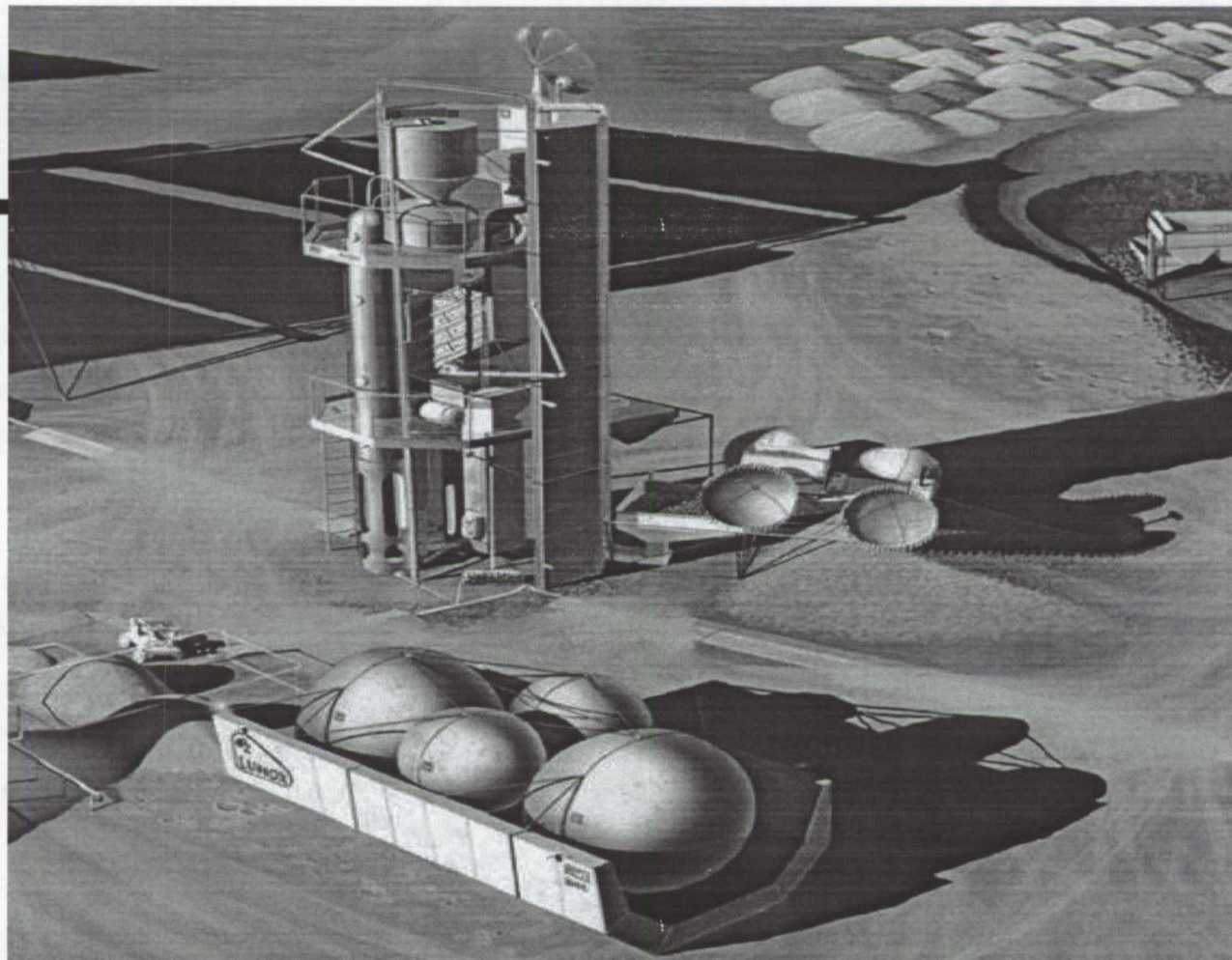


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Oxygen Production System Models for Lunar ISRU

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Abstract.

In-Situ Resource Utilization (ISRU) seeks to make human space exploration feasible by using available resources from a planet or the moon to produce consumables, parts, and structures that otherwise would be brought from Earth. Producing these in situ reduces the mass of such that must be launched and doing so allows more payload mass for each mission. The production of oxygen from lunar regolith, for life support and propellant, is one of the tasks being studied under ISRU. NASA is currently funding three processes that have shown technical merit for the production of oxygen from regolith: Molten Salt Electrolysis, Hydrogen Reduction of Ilmenite, and Carbothermal Reduction.

The ISRU program is currently developing system models of the abovementioned processes to: (1) help NASA in the evaluation process to select the most cost-effective and efficient process for further prototype development, (2) identify key parameters, (3) optimize the oxygen production process, (4) provide estimates on energy and power requirements, mass and volume of the system, oxygen production rate, mass of regolith required, mass of consumables, and other important parameters, and (5) integrate into the overall end-to-end ISRU system model, which could be integrated with mission architecture models. The oxygen production system model is divided into modules that represent unit operations (e.g., reactor, water electrolyzer, heat exchanger). Each module is modeled theoretically using Excel and Visual Basic for Applications (VBA), and will be validated using experimental data from on-going laboratory work. This modularity (plug-n-play) feature of each unit operation allows the use of the same model on different oxygen production systems simulations resulting in comparable results. In this presentation, preliminary results for mass, power, volume will be presented along with brief description of the oxygen production system model.



Outline



- Why are systems models important?
- Description of oxygen production processes
- System models: A modular approach
- System model results
- Acknowledgment



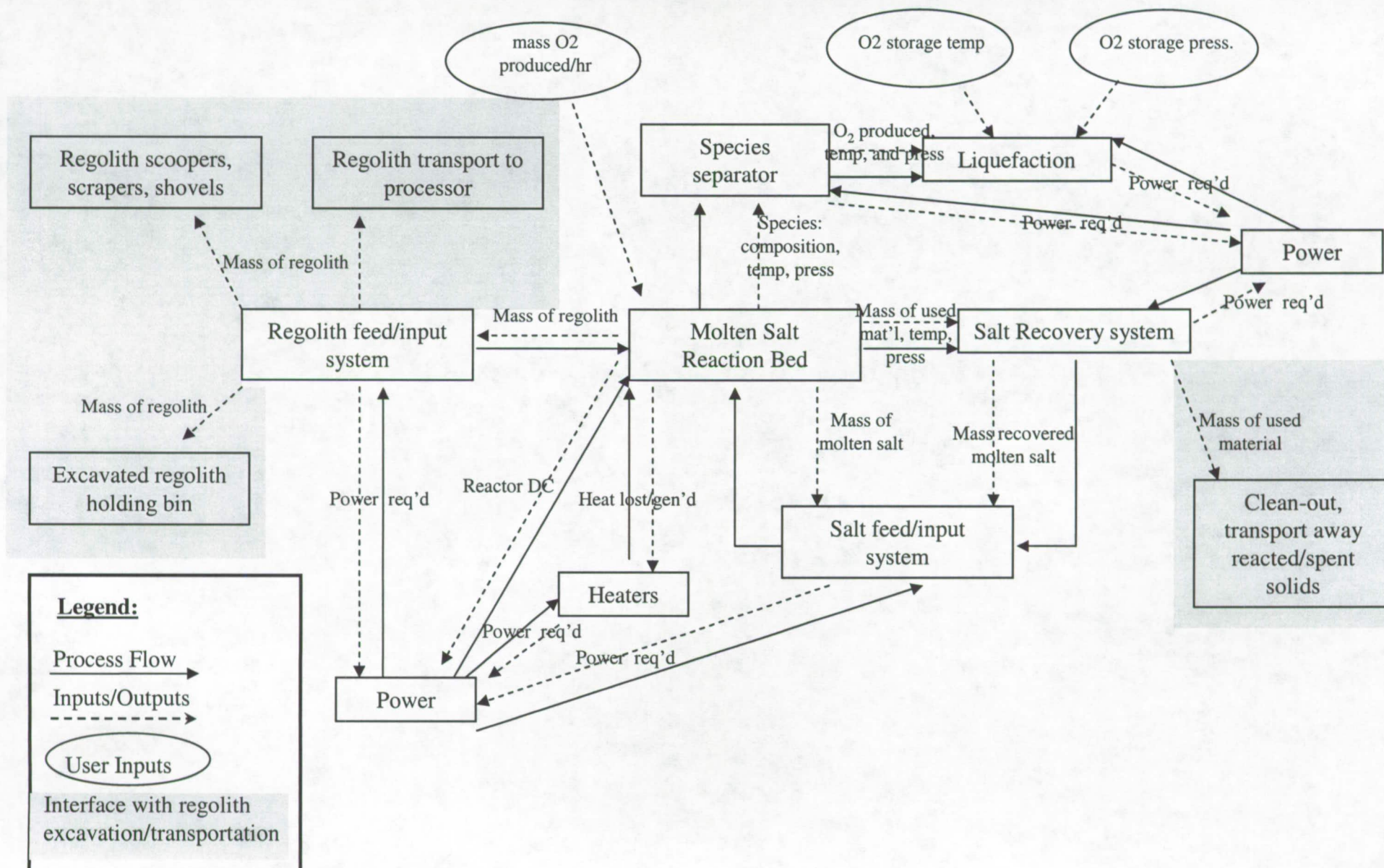
Why are system models important?



- Identification of technology needs:
 - Source of thermal power other than electrical (i.e. solar concentrator)
 - Heat recovery from spent regolith
- Hardware design:
 - Significant (~30%) mass reduction are achieved if a multi-reactor system is used. The multi-reactor system reduces the mass of the equipment downstream from the reactors due to a more steady-state like operations
- Optimization:
 - Models can supplement experimental work by providing optimal operating parameters

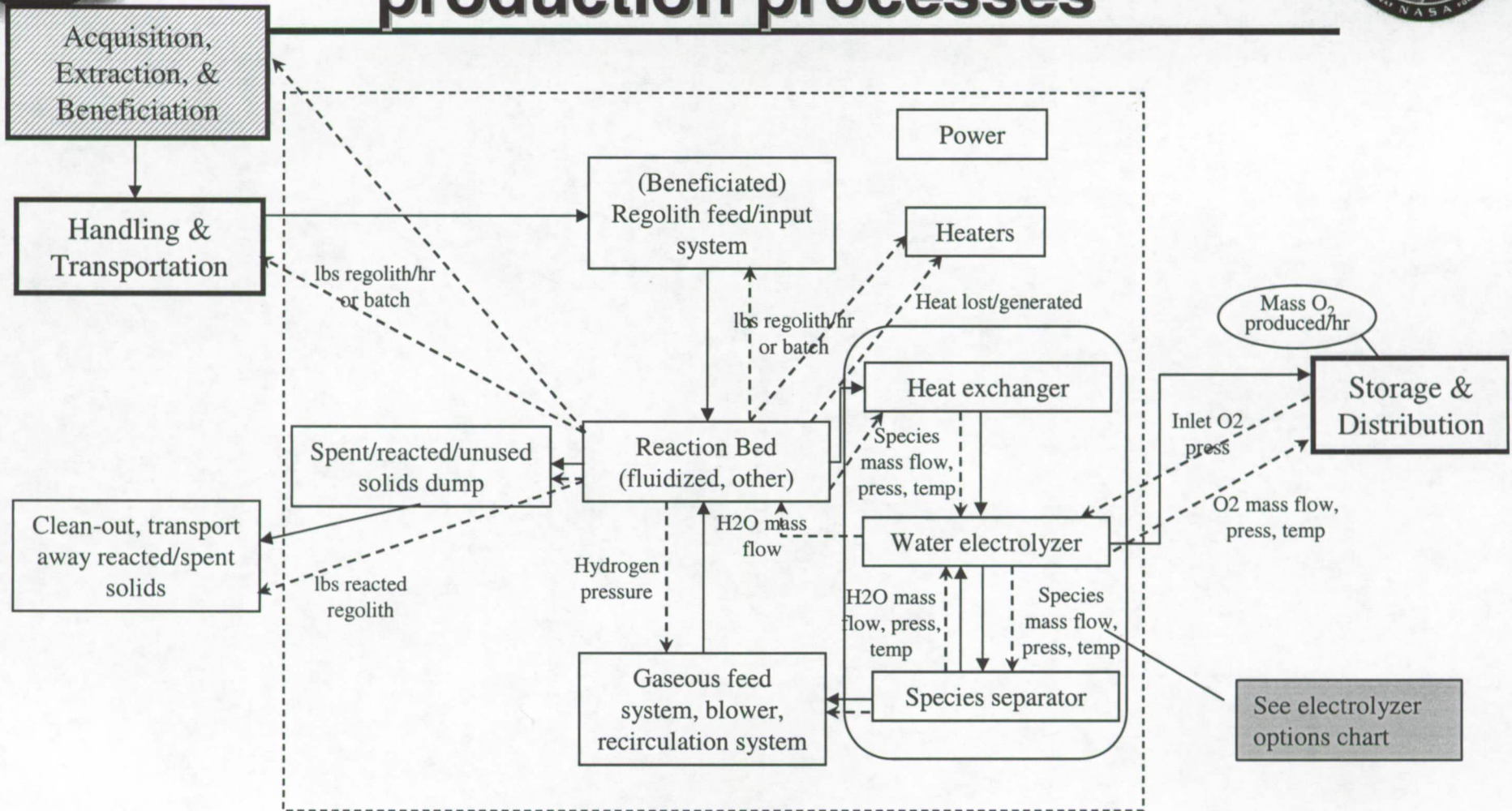


Description of oxygen production processes





Description of oxygen production processes



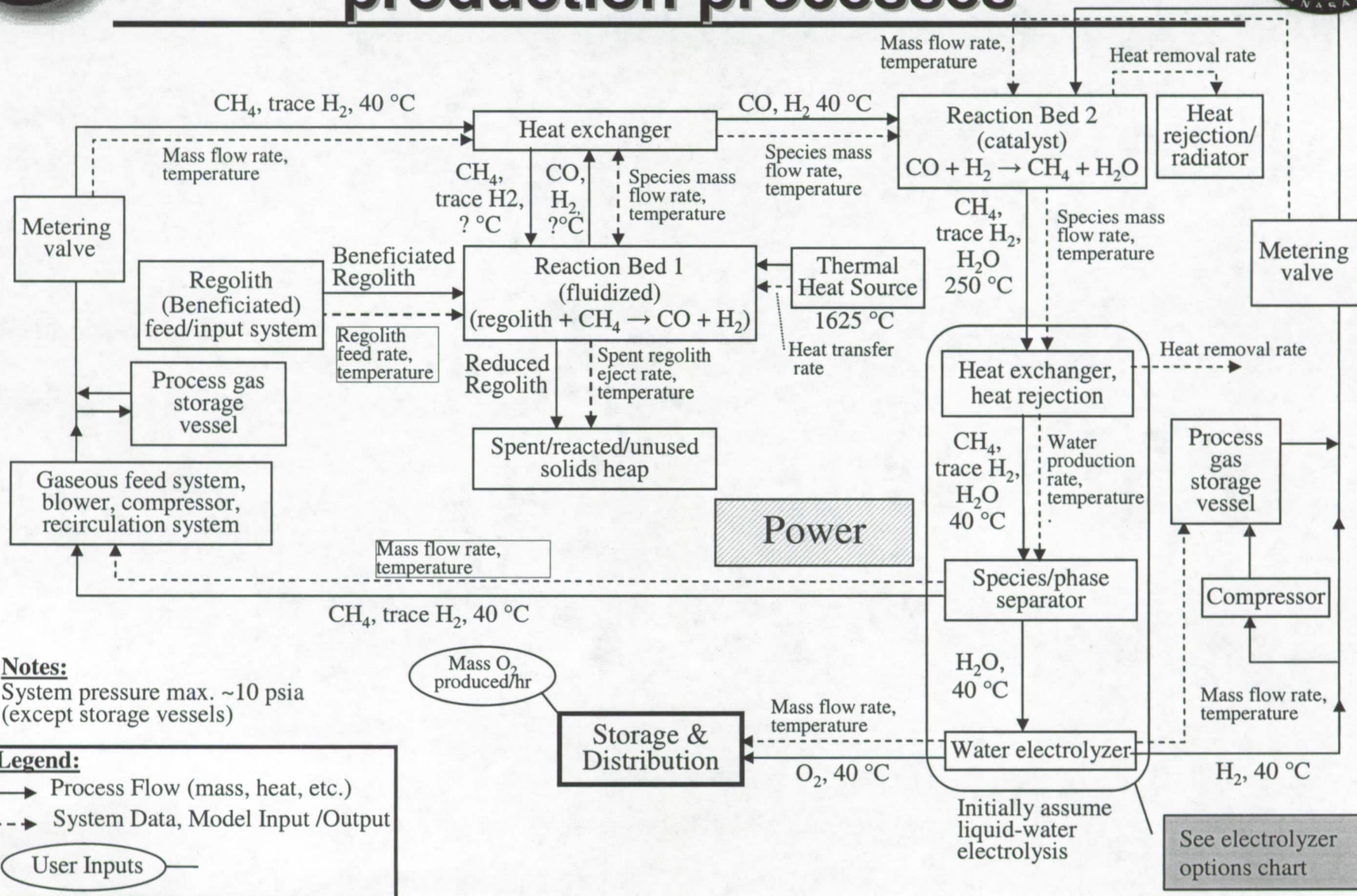
Legend:

- > Process Flow (mass, heat, etc.)
- -> System Data, Model Input /Output

User Inputs

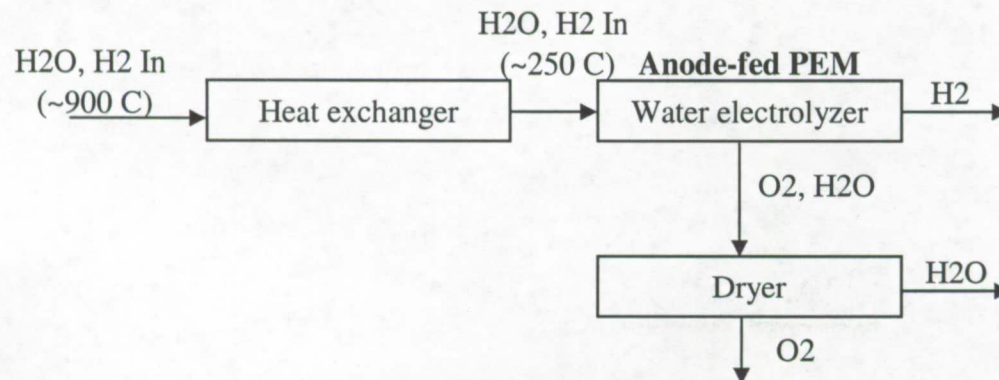
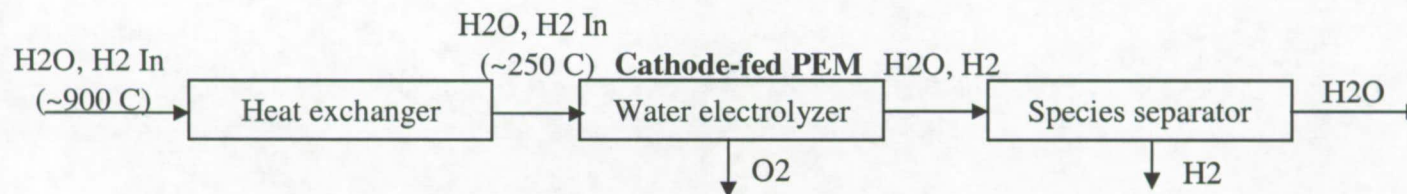
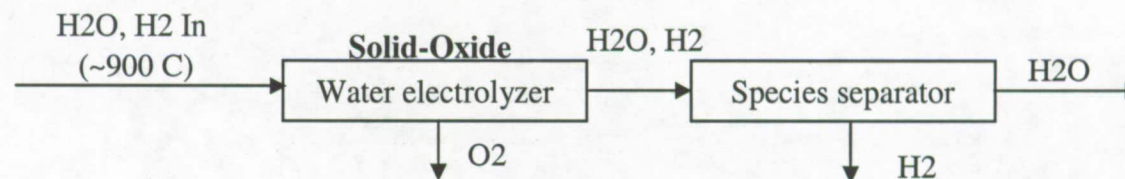


Description of oxygen production processes





Description of oxygen production processes





System Model: A Modular Approach

ISRU System Level



Mission Requirements:

- Number of missions
- Number of EVAs
- Description of outpost

Mission Requirements

ISRU System Output

ISRU System Output:

- System Mass
- System Volume
- System Power

Inputs:

- Oxygen production rate
- Location of O₂ plant
- O₂ production process

Inputs

Outputs

Outputs

Inputs

Inputs:

- Regolith excavation rate
- Location of excavation site
- Location of O₂ plant
- Type of excavator/transporter

O₂ Production
System
KSC

Excavation
System
GRC

Outputs:

- Regolith required
- System mass
- System power
- System volume

Outputs:

- System mass
- System power
- System volume

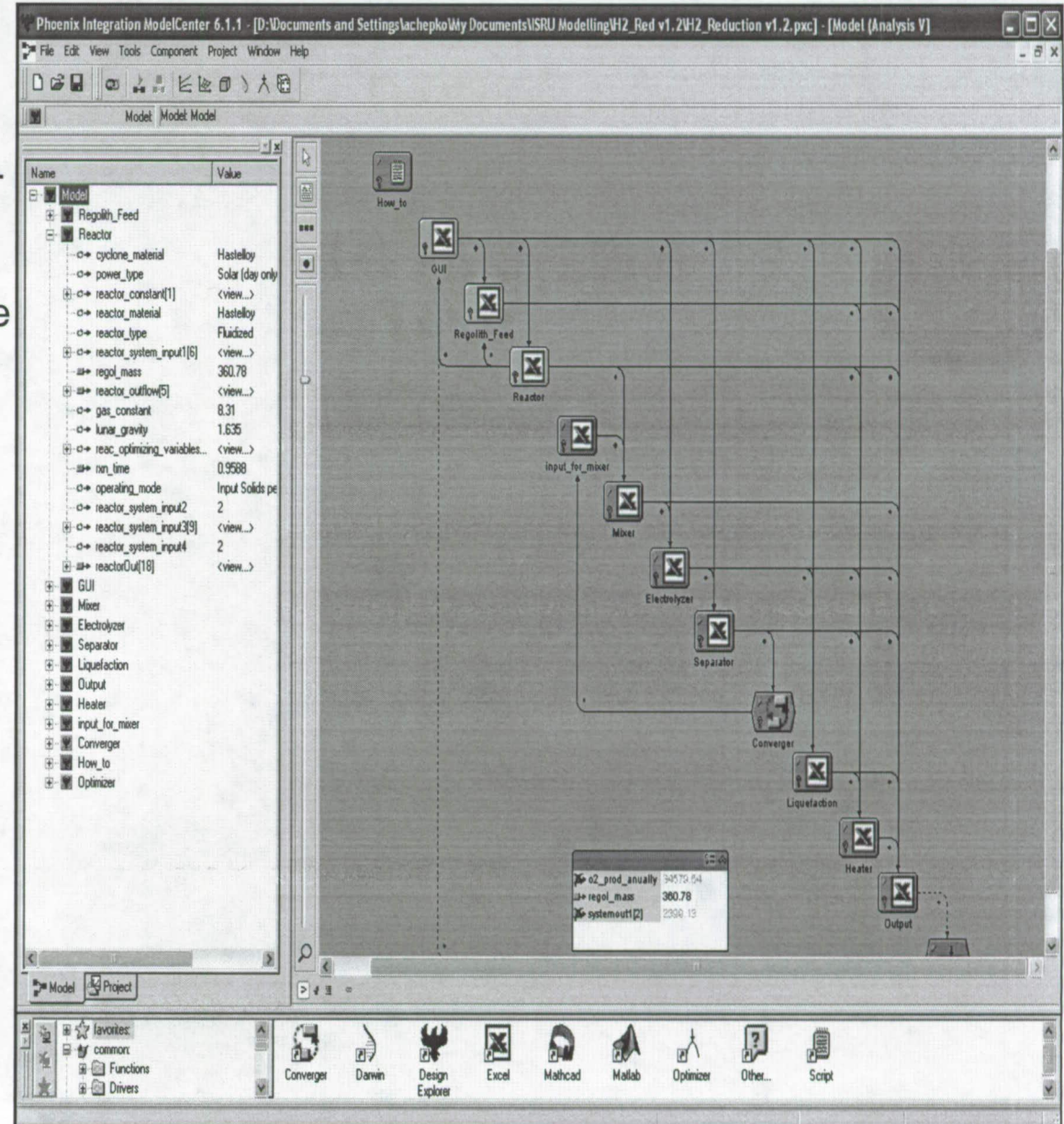


System Model: A Modular Approach

O₂ Production System Level



- Each oxygen production process is divided into modules or unit operations
- Each module is modeled in a standalone Excel workbook using Visual Basics for Application (VBA)
- An Excel worksheet functions as the Input/Output interface (Databus)
- A VBA module is used to build a 'master' equation where the calculations are performed
- Modules are linked using Phoenix Integration ModelCenter
- Each link represents information passed from one module to the other
 - The information is passed in the form of
 - individual cell
 - array of cells
 - Each cell or groups of cells is given a specific name (aka: Named Range)





System Model: A Modular Approach

O₂ Production System Level cont'd



The Named Ranges have a hierarchy:

- **Inputs:**

- **Global_input:** all constants and quantities that are specified at the system level:

- Lunar Environment
 - Required O₂ Production
 - Constants

- **Inflow:** all input values a component requires that come from another component

- Temperature
 - Pressure
 - Flow rates

- **Design_input:** all other input parameters required to run a component but are not generated by other model components.

- Vessel diameter
 - Material of construction

- **Outputs:**

- **Global_output:** all calculated values pertinent to overall model's conclusions:

- Mass
 - Power
 - volume

- **Outflow:** all calculated output values that other components require

- Temperature
 - Pressure
 - Flow rates

- **Design_output:** all other calculated output values that describe component specifics but are not required by other components.

- Vessel height

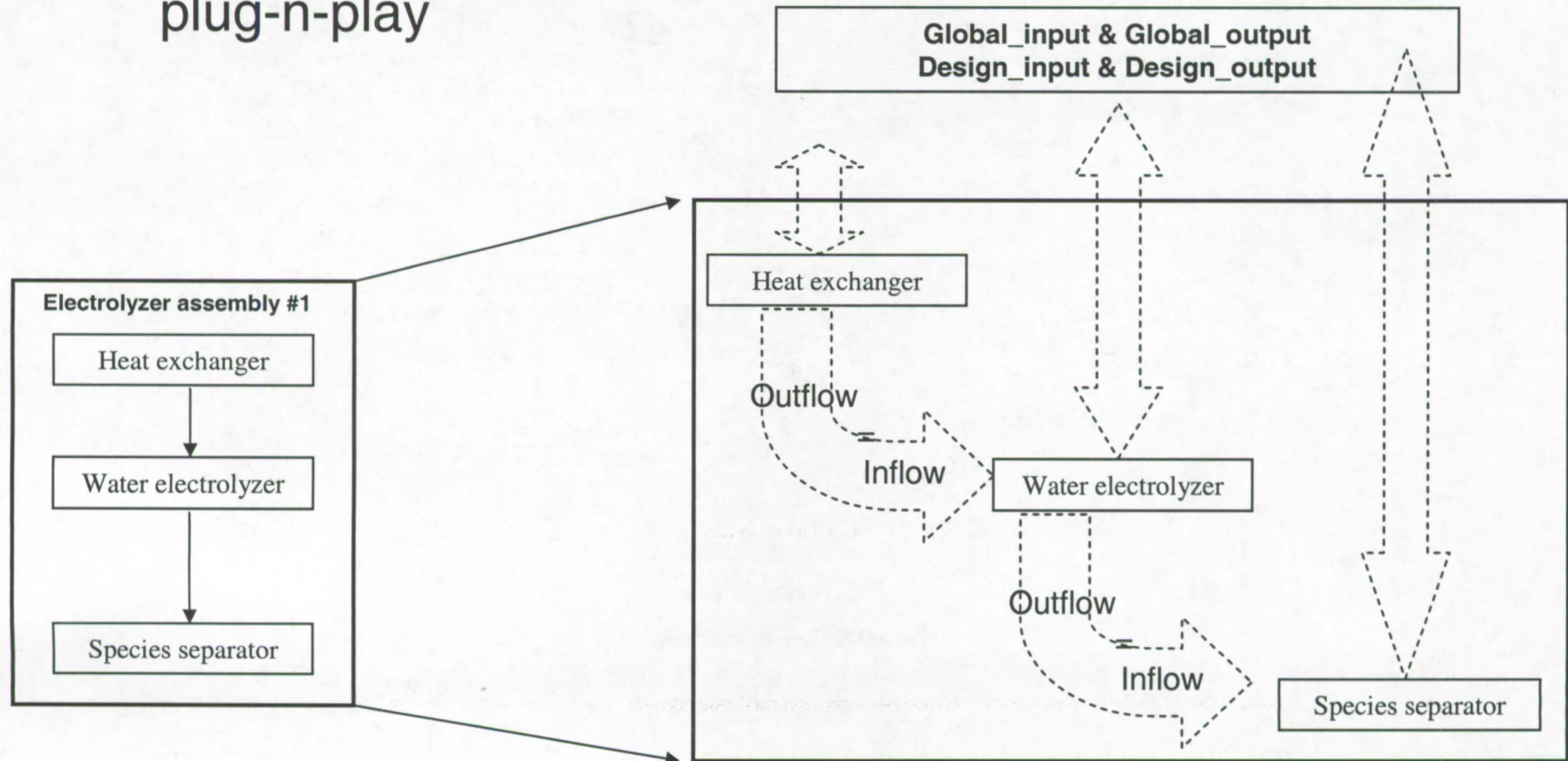


System Model: A Modular Approach

O₂ Production Sub-System Level



- The Named Range creates a common interface for the modules
- This common interface enables the modules to be plug-n-play





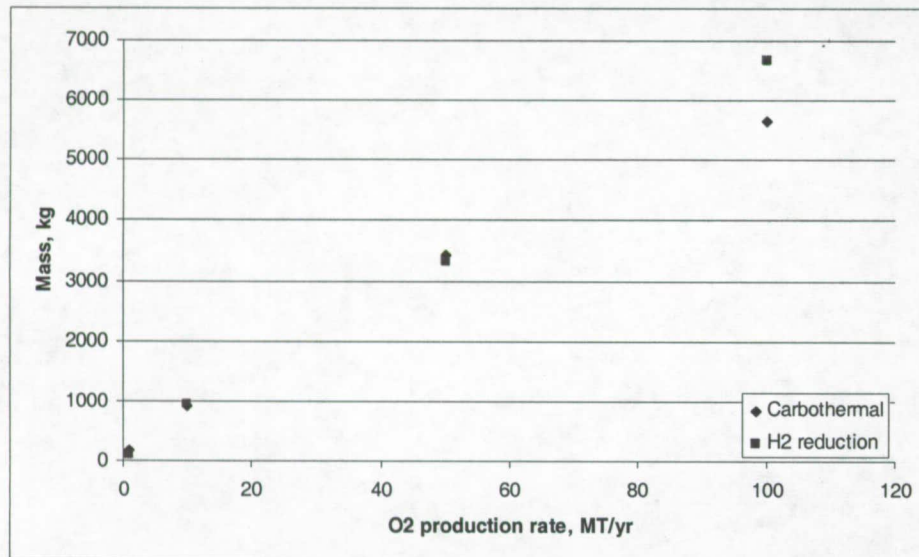
System Model Results: “Baseball Cards”



- “Baseball Cards”?
 - ISRU study to support the Lunar Architecture Team (LAT) during Phase I study
 - Provided inputs of Mass-Power-Volume for ISRU systems
 - O₂ production from regolith
 - Excavation
 - Volatile extraction
 - O₂ production from Lunar water
 - And others
- Ground Rules for O₂ production from regolith:
 - Processes: H₂ Reduction and Carbothermal Reduction
 - Two locations: Equatorial and Polar regions
 - O₂ production rates: 1, 10, 50 and 100 MT/yr
- Assumptions:
 - Power Assumptions:
 - Thermal power is provided by solar concentrator
 - Electrical power is provided by photovoltaic cell
 - Location Assumptions :
 - Equatorial: 50% operating time (183 Earth-days/Earth-year), Mare regolith composition
 - Polar: 70% operating time (255 Earth-days/Earth-year), Highland regolith composition
 - Mass Assumptions:
 - Piping and structural mass is 20% of module mass
 - Growth potential of 20%

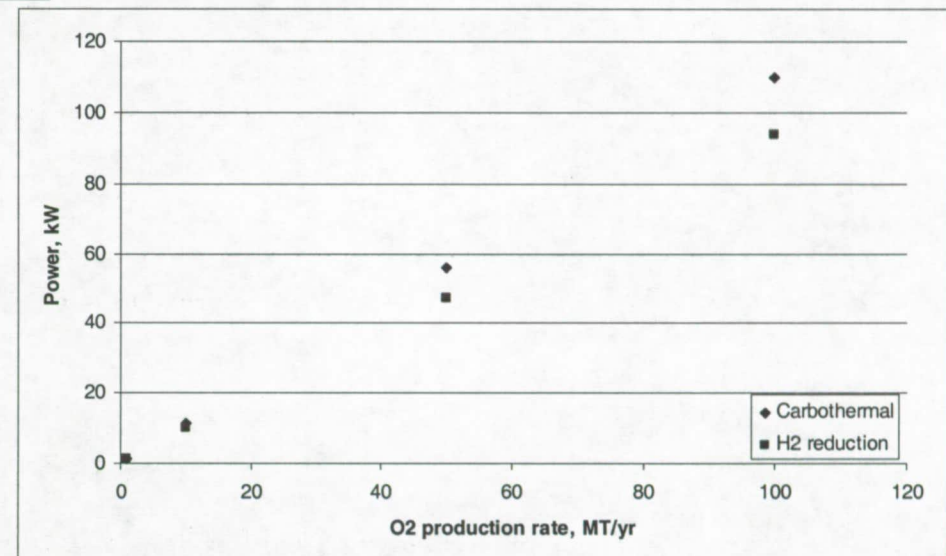


System Model Results: “Baseball Cards” cont’d



- Both O₂ production systems have similar mass and power consumption
- The deviation at higher production rate could have resulted from the modules running outside the validated range

- A more realistic production rate is probably <10 MT/yr:
 - 8 MT/yr for propulsion
 - 2 landers per year
 - 2 MT for life support
 - Outpost of 4 crew members
 - EVA's



NOTE: Assumes thermal energy to the reactor is provided via solar concentrator



Acknowledgements



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